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Protecting the Environment in the Space Age: GIS at the John F. Kennedy Space Center

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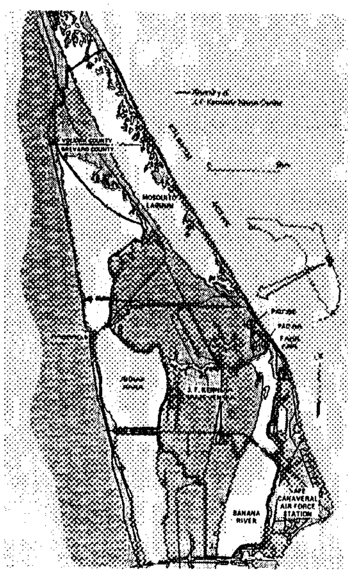

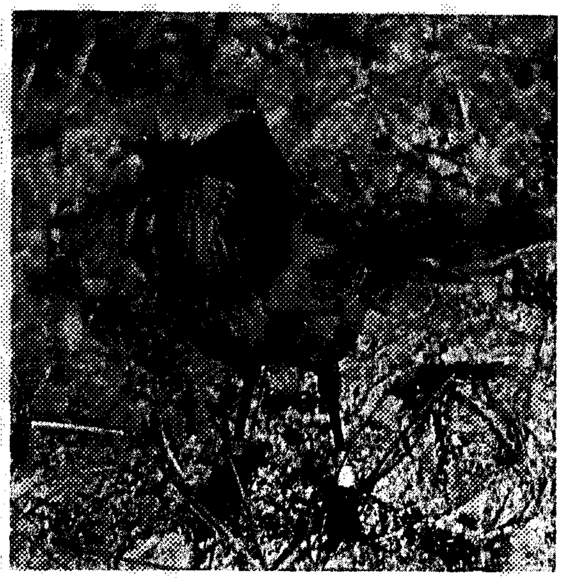

Figure 1. Kennedy Space Center is located on the central east coast of Florida.
Figure 2. Listed as a federally threatened species by the U.S. Fish and Wildlife Service, a banded Florida scrub jay is shown in preferred habitat with sand openings.

The Biomedical Operations and Research Office (MD) of the National Aeronautics and Space Administration (NASA) is using geographic information systems (GIS) technology in its effort to monitor protected wildlife at Kennedy Space Center (KSC). Data bases containing environmental variables and demographic data have been compiled for a number of threatened and endangered species on KSC, along with data bases showing the effects of Space Shuttle launches on KSC. NASA also uses GIS technology to monitor such episodic environmental impacts as Space Shuttle launch exhaust deposition.

Increased urbanization has reduced the amount and quality of natural habitat in Florida. As urbanization increases, so does the importance of protected lands in the state. Kennedy Space Center (KSC) is the largest protected area on the east coast of Florida and is home to 14 federally listed and 15 state-listed wildlife species identified as threatened or endangered. The National Aeronautics and Space Administration (NASA) has particularly challenging management goals that include using the land for space operations and preserving the valuable habitat contained within KSC. Geographic information systems (GIS) technology is one of the many tools being used to meet those management goals by mapping and monitoring environmental variables and long-term demographic data sets on selected animal species.

KSC, the principal launch site for NASA space systems, is centrally located on the east coast of Florida (Figure 1), where the initial trajectories of space transport systems are over the Atlantic Ocean. NASA began acquiring land in early 1962 on north Merritt Island, Florida, as a base for launch operations in support of the Manned Lunar Landing Program. KSC now encompasses 57,000 hectares — 140,000 acres — which is considered extensive enough to provide surrounding communities protection from launch operations.

KSC is long and narrow, bordered by the Indian River Lagoon on the west and Cape Canaveral Air Force Station (CCAFS) and the Atlantic Ocean on the east. Merritt Island and Cape Canaveral are a barrier island complex of Pleistocene and Recent ages. The topography consists of a series of ridges and swales derived from relict dunes deposited as the barrier islands were formed. Elevation ranges from sea level to as much as nine meters on the most recent dunes.

Because KSC was found to include prime habitat for unique and endangered flora and fauna, NASA entered into an agreement with the U.S. Fish and Wildlife Service (USFWS) to establish a wildlife preserve, known as the Merritt Island National Wildlife Refuge (MINWR), within the boundaries of KSC. A similar agreement was reached with the Department of the Interior to form the Canaveral National Seashore (CNS), managed by the National Park Service (NPS), within KSC's northern boundaries. The majority of KSC land is undeveloped, with only five percent being used for NASA operations and industrial use. The remaining 95 percent is managed by USFWS and NPS.

KSC is located in a transition zone between the warm temperate Carolinian Zoogeographic Province to the north and the subtropical Caribbean Zoogeographic Province to the south. The result of this location is high biodiversity with species from each region being present. There are more than 1,500 taxa — or biological groupings — on KSC, including 115 species of fish, 315 species of birds, 65 species of amphibians and reptiles, 25

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species of mammals, and almost 1,000 species of vascular plants (NASA, 1990; NASA, 1992).

The Biomedical Operations and Research Office (MD) of NASA has been supporting environmental monitoring and research on KSC since the early 1970s. Program elements include monitoring of baseline conditions to document natural variability in the ecosystem, assessments of operations, assessments of new facilities construction, and ecological research focusing on wildlife habitat associations. The ecological program's objective is to develop information necessary to define and predict environmental problems and impacts that may result from activities at KSC. To support these requirements, the ecological program uses a proactive, long-term, multidisciplinary approach (Hinkle et al., 1988).

Remote sensing and GIS technologies are at the center of the environmental monitoring and research activities on KSC. ARC/INFO (Environmental Systems Research Institute [ESRI], Redlands, California, USA) software is used for analyzing both episodic and continuous environmental impacts, as well as threatened and endangered species' demographic–habitat relationships. This process enhances our predictive capability to minimize or mitigate potential environmental impacts on the center.

APPLICATIONS

Data bases containing environmental variables and demographic data have been compiled for a number of threatened and endangered species on KSC. We have focused our energy and resources on species with habitats having the highest probability of being affected by NASA operations and those that are indicators for other species of special concern. Data bases showing the effects of Space Shuttle launches on KSC have also been produced. Following are examples of these data bases.

Florida scrub jay. Field biology, remote sensing, and GIS methods are combined to map habitat features important for one of the most habitat-specific birds in North America. The Florida scrub jay (*Aphelocoma coerulescens coerulescens*), shown in Figure 2, is a threatened species restricted to oak-dominated scrub, which occurs mostly on well-drained soils in the central

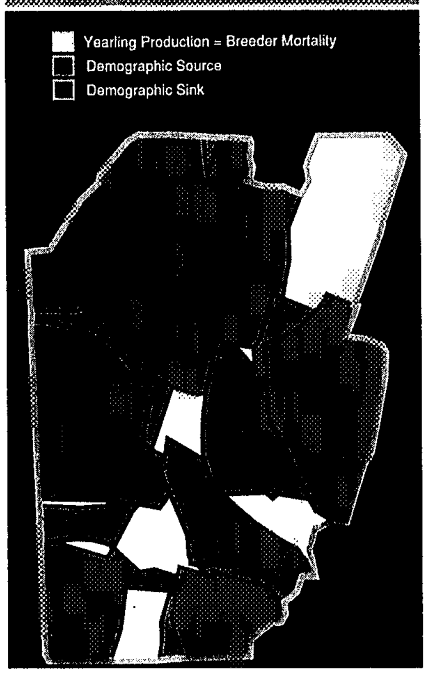

Figure 3. Scrub jay source and sink areas created from overlaying 1989–1991 yearling production and breeder mortality coverages for the Tel-4 long-term study area

Florida peninsula. These birds live in territories defended year-round by a permanently monogamous breeding pair and young scrub jays called helpers (Woolfenden and Fitzpatrick, 1984).

Urbanization of well-drained ridges throughout Florida has caused a major decline in suitable scrub jay habitat. The result of this habitat destruction and degradation is that KSC is now home to one of the largest remaining Florida scrub jay populations (Breininger, 1989). Proper management of this habitat is critical for the scrub jay's survival.

A data base containing both environmental variables and long-term demographic data has been produced for two study areas on KSC. Habitat maps have been produced using very large-scale, false-color aerial imagery and a detailed Anderson Land-use/Landcover classification system. Each scrub jay in the study areas has been banded using a unique combination of two-color bands and an aluminum USFWS band. Territory boundaries were mapped during April and May using repeated visits to determine the area defended by each family. Nearly all the nest attempts within the study boundaries

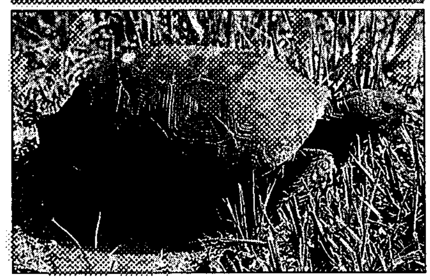

Figure 4. The gopher tortoise is listed as a species of special concern by the Florida Game and Fresh Water Fish Commission.

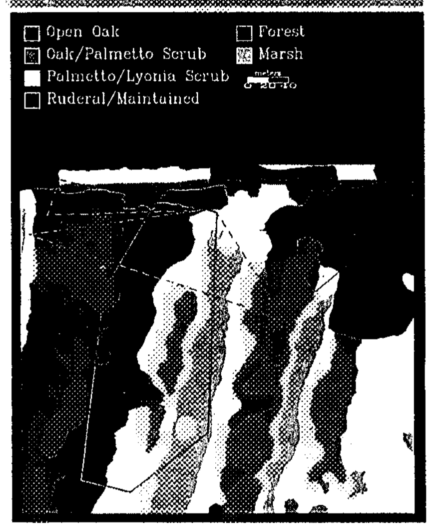

Figure 5. Each gopher tortoise home-range polygon was created by overlaying all burrows used by individual tortoises and connecting the outermost burrows. Solid and dashed arcs represent male and female tortoise home ranges, respectively, and are shown here overlaid on habitat polygons.

during each nesting season were located and mapped. These maps were digitized into separate coverages representing each season, and demographic attributes were stored along with their corresponding spatial locations and areas.

Territories, nest locations, and demographic data were overlaid on the habitat map and other environmental layers to gain further insight into the scrub jay's habitat requirements. Some of the analyses were as simple as calculating arithmetic means of territory sizes and acreages of habitat types within territories for each year. Some analyses involved demographic data entirely, such as differencing breeder mortality and yearling production to produce coverages of source (areas where yearling production exceeds breeder mortality) and sink (areas where breeder mortality exceeds yearling production) locations, as shown in Figure 3. Other, more analytical techniques involved determining correlations and associations between habitat and demographic variables. These studies allow the development and testing of habitat models for environmental assessments and mitigation of environmental impacts on KSC. GIS techniques enhance the mapping and delineation of the most important areas for maintaining a viable Florida scrub jay population on KSC, thereby enhancing land-use planning activities (Breininger, et al, 1991).

The gopher tortoise (*Gopherus polyphemus*) is a 3.5- to 4.5-kilogram animal, shown in Figure 4, that can be found from extreme southern South Carolina and eastern Louisiana through much of mainland Florida. The tortoises occupy a variety of habitats but require areas with an adequate cover of herbaceous plants for food and suitable soils in which to dig burrows (Cox et al., 1987). Burrows provide protection from fires, predators, and harsh climatic conditions. In addition, at least 39 invertebrate and 42 vertebrate species have been documented using gopher tortoise burrows. A combination of habitat destruction, predation by humans and other animals, and unique biological characteristics have placed the gopher tortoise's continued existence in jeopardy. It is listed as a "species of special concern" by the Florida Game and Fresh Water Fish Commission (Wood, 1986).

KSC is the largest area of protected habitat for the gopher tortoise on the Atlantic coast of Florida (Breininger et al., 1988). A radio telemetry study was done at two sites on KSC between 1987 and 1989 to answer questions about habitat and burrow use. Twenty-three tortoises were trapped, outfitted with transmitters, and tracked twice per week for an average of 10 months. Burrow locations for the tagged tortoises were digitized from color infrared aerial photographs into the GIS. Because a single tortoise uses several burrows within an area, home-range polygons were developed for each animal based on the burrow locations. Individual home-range sizes were determined, as well as average home range sizes for males and females.

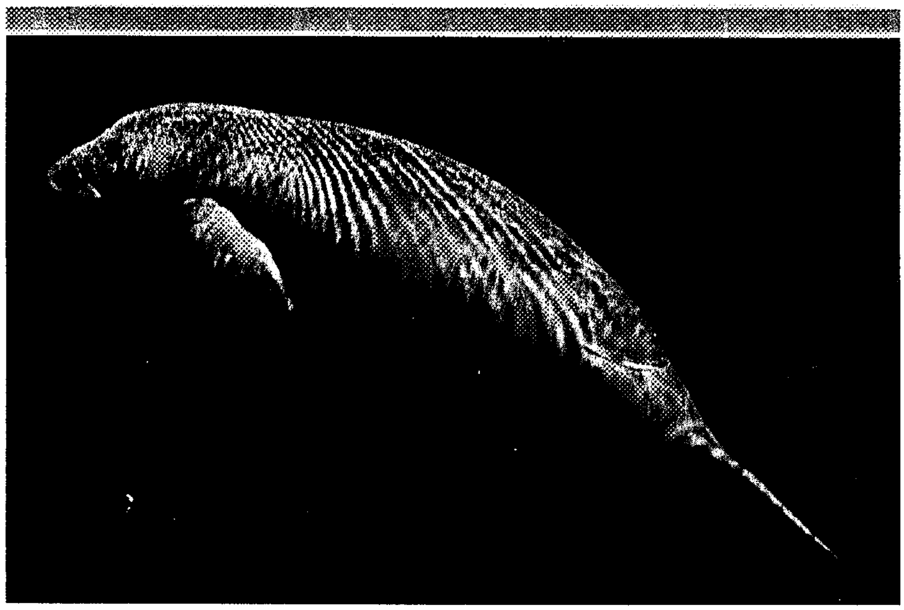

Figure 6. The West Indian manatee is listed as an endangered species by the U.S. Fish and Wildlife Service.

The home range polygons were overlaid onto vegetation coverages to examine the types and amounts of habitats within them, as shown in Figure 5. These data, when considered with other information — for example, the number of burrows used per tortoise, as well as seasonal activity — provide a visual representation of tortoise habitat use that cannot be achieved with numbers alone. Results can be used to estimate population sizes and determine critical habitat requirements, both of which are important considerations for a species so greatly influenced by land management practices.

The West Indian manatee (*Trichechus manatus*), shown in Figure 6, sometimes called the Florida manatee, was federally listed as an endangered species in 1972. Manatees are basically estuarine in Florida, although they are occasionally seen along the beaches. Manatees are migratory and can range in excess of 820 kilometers (Reid, 1991). They are found throughout Florida and southeastern Georgia and occasionally along coastal states farther north and west.

Manatees have always been found in the surrounding waters of KSC, with the highest peak during spring and a smaller surge during fall. In 13 years of monitoring, a five-fold increase of manatees using KSC waters during spring has been documented. The spring peak in recent years has included more than 300 manatees within the KSC boundaries of the Banana River (Provancha and Provancha, 1988). The increased use of KSC waters by manatees appears to manifest a shift away from previously used areas and reflect the degradation of habitat outside protected areas. Manatee mortalities have increased at an alarming rate in Florida, with human development and boating activities being the main causes (Beck et al., 1982).

Figure 7. Summer manatee sightings for 1977 through 1991 overlaid on a Landsat scene. Clustered sightings indicate preferred habitat locations during summer season.

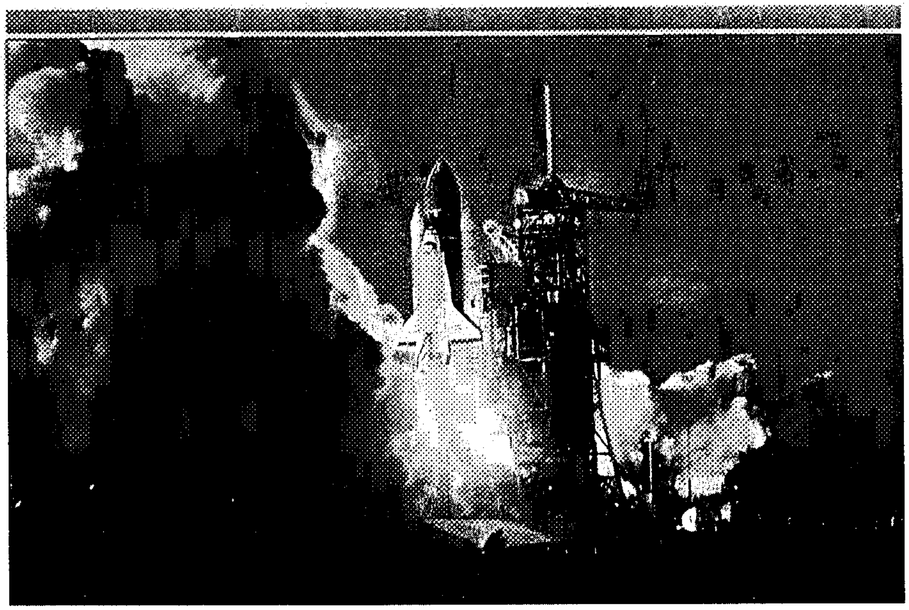

Figure 8. A Space Shuttle blasts off from Kennedy Space Center, causing the formation and dispersion of an exhaust cloud.

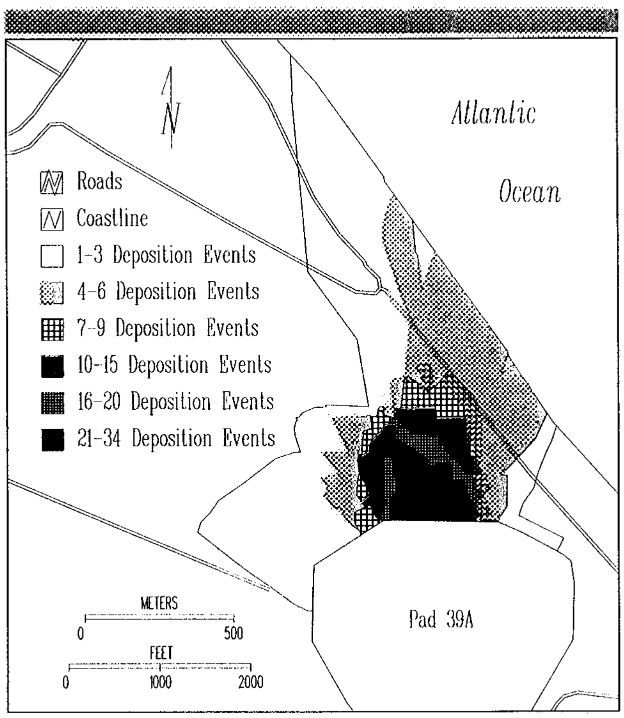

Figure 9. Cumulative Space Shuttle near-field exhaust deposition pattern for Pad 39A. Frequent deposition events occur close to the pad and decrease with distance.

All open water on KSC deeper than one meter is potential habitat for the manatee, but extensive seagrass beds bordering deep basins are preferred. Fresh water sources also attract manatees; some researchers believe fresh water to be a requirement.

Since 1977, aerial surveys have been conducted over KSC waters to monitor the number and distribution of manatees. Surveys are conducted with light planes or helicopters using a set flight path. During the early surveys, observers would call out sightings and any behavior associated with them and a person would mark the data on a map. These maps were stored in a file drawer until 1989, when they were digitized into ERDAS (Atlanta, Georgia, USA) image processing software and converted into ARC/INFO using GENERATE to produce a point coverage. Problems with this procedure such as positional accuracy, map accuracy and points being omitted during digitization have forced more automated techniques to be used. Since 1990, an Apollo II loran unit (II Morrow, Inc., Salem, Oregon, USA) combined with a Toshiba T1100 Plus (Toshiba Corp., Irvine, California, USA) portable computer have been used during surveys. The computer operator hits a key on the computer and types in the attributes of each sighting. After each survey, the data are converted through dBase IV (Ashton-Tate, Torrance, California) into ASCII format with latitude and longitude conversions to State Plane coordinates performed in ERDAS. The data are then loaded into ARC/INFO via the GENERATE and ADD FROM commands. This technique is much easier and more time efficient than its predecessor.

Our GIS has provided a means for storage and analysis of a large, long-term, and comprehensive manatee data base (Figure 7). The GIS data allow NASA and the USFWS to track manatee time and space interactions, which are important for performing facilities assessments on KSC. By using this valuable information, NASA can manage KSC activities to minimize impact on the manatee's fragile habitat.

LAUNCH DEPOSITION MONITORING

NASA also uses GIS technology to monitor such episodic environmental impacts as Space Shuttle launch exhaust deposition. Space Shuttle launches produce localized acidic deposition through the formation and dispersion of an exhaust cloud, shown in Figure 8. The cloud contains carbon dioxide, aluminum oxide, and hydrogen chloride, along with additional minor components. These cloud constituents, when combined with water vapor and 300,000 gallons of sound suppression and cooling water dumped on the pad at the time of launch, produce acidic deposition (Anderson and Keller, 1983). Typically this cloud is directed northward by a flame trench and then rises to a stabilization height and is carried by prevailing winds.

Two divisions of deposition exist: near-field and far-field. Near-field deposition occurs on the immediate north side of the launch pad and involves the highest concentration of acid. Far-field deposition occurs after the cloud rises and moves with prevailing winds. Areas receiving far-field deposition, which is primarily dry residue, vary with meteorological conditions and occur farther away from the pad. Both near- and far-field deposition are mapped by field survey after each launch event.

The near-field and far-field maps from each launch are digitized into the GIS (for example, Duncan and Schmalzer, 1992). Individual maps of the deposition are combined to produce cumulative deposition patterns for both Shuttle launch facilities (Figures 9 and 10). Three different maps are continually updated, near-field maps for launch pads 39A and 39B and a combined far-field map for both pads.

Cumulative maps of deposition reveal the frequency of deposition at any given location on KSC from the 11 years of Shuttle launches, as well as which launches are responsible for that deposition. The data base can be updated after each launch, producing a continuous source of spatial information to determine and monitor the frequency of cumulative deposition, which has implications for both operational uses and habitat management for the flora and fauna of KSC.

CONCLUSION

NASA is committed to protecting the environment of KSC while continuing to launch space transport systems. Proper management and monitoring of this protected land is increasingly important and must be based on sound scientific data. GIS methods have enhanced NASA's ability to monitor and manage natural resources on KSC by providing an efficient means of data storage and spatial–numerical analysis. The ongoing long-term studies currently underway on KSC produce large quantities of spatial data and even larger quantities of relational data.

GIS technology is increasing the ability of scientists on KSC to analyze their data in a spatially explicit manner and gain greater insight into spatial, temporal, habitat, and animal interactions necessary for proper management. By doing so, we are moving in a direction to produce spatial predictive models that will aid in impact assessment and land mitigation practices necessary for cohabitation of wildlife with ongoing space operations.

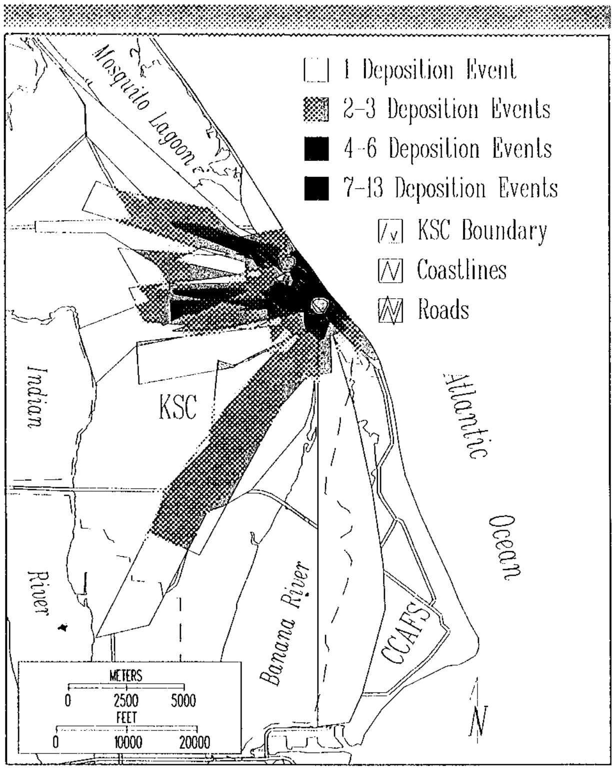

Figure 10. Cumulative Space Shuttle far-field exhaust deposition for both pads 39A and 39B. Far-field deposition occurs over a much larger area than near-field deposition but occurs less frequently at any one location.

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